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HYDRAULIC PERFORMANCE EVALUATION OF MICRO IRRIGATION SYSTEM FOR AEROBIC RICE CULTIVATION

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Original Article

ABSTRACT

The present era of agriculture has been witnessing an acute shortage of irrigation water owing to the unscrupulous pumping of aquifers coupled with over exploitation of surface water storages. For instance it is not uncommon to observe depleted aquifers with their well water levels deeper than 100 m in most parts of Tamil Nadu with particular reference to rice belts except Thanjavur deltaic area where drainage problem persists due to water table nearer to surface.

This situation of water shortage has resulted in exploring the possibilities of sustaining rice production under aerobic conditions, in a technically feasible and economically viable combination of rainwater harvesting systems and micro irrigation systems, incorporating fertigation and chemigation, as the state of art technology for popularization among the farming community in order to make them realize the situation of emergency for a judicious use of available water resources.

The hydraulic gradients all over the micro irrigation system along with soil moisture distribution uniformity have been developed.

Contours of Soil moisture distribution were drawn by using 'surfer' package of Windows version for the field drip irrigation layout where the drip emitters are laid at a depth of 5-10 cm and 10-15 cm and irrigation done by using solar operated pump (S1) and open submersible pump (S2).The Moisture distribution was more in the treatment (S1) and the maximum moisture content was found to be at the location where the wetting circles overlapped by two emitters. It was because of the lateral laid at the sub surface. The maximum and minimum moisture content on % dry basis immediately after irrigation for different treatments were found T1 (27.06, 20.10), T2 (29.63, 19.62), T3 (31.52, 22.19), T4 (25, 20.75) for solar operated irrigation(S1).T1 (24.55, 18.43), T2 (24.09, 12.89), T3 (23.87, 11.62), T4(25.14, 11.70) for irrigation by open submersible pump(S2).

All the three fertilizers viz., Nitrogen, Phosphorus and Potassium were supplied through fertigation in the form of water soluble fertilizers once in a week. In case of N and K the recommended dose of fertilizers was given in four equal splits at basal, tillering, panicle initiation and first flowering stages.

The treatment (T1) with 0.8 m lateral spacing and lateral depth of 5-10 cm and variety(V2) JKRH 333(Hybrid) and irrigation by solar operated pump (S1) was found to register the maximum yield at 6.17 t/ha at 5 % significance level.

The water use efficiency for all the treatments were worked out, taking in to account the amount of total water applied during the crop period. Higher WUE of 15.917 kg ha^{-1}mm^{-1} was recorded in drip irrigation at 0.8 lateral spacing and lateral depth of 5-10 cm (T1) with variety 2 and solar irrigation (S2), closely followed by lateral spacing of 0.8m (T1) with the same variety 2 and well Submersible pump (S2) WUE of 14.542 kg ha^{-1} mm^{-1}. It was because of higher yields

obtained due to optimum supply of irrigation water

KEYWORDS: Aerobic Rice, Frictional Losses & Head Loss

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INTRODUCTION

Food security in the prevailing situation of exponential growth rates of population, across the globe, warrants a proportionate increase in crop production with variable strategies. Land and water remain the indispensable bases, to sustain productivity in tandem, with improvised packages of practices including judicious usage of water and nutrients, besides an integrated plant protection component.

On par with wheat, Tamil Nadu is one of the rice producing states of India. In India rice is the principal food grain. The current scenario of rice production in different states of India is depicted as follows.

Traditionally, rice has been construed as a water loving crop, with its seasonal water requirement ranging from 1200 mm to 1600 mm, including the water usage for land preparation and the inevitable deep percolation losses, in the conventional system of level basin, confined by compartmental bunds permitting gravitational flooding from basin to basin. Water is always present on the soil surface, surrounding rice crop. The sub surface irrigation experiences, super saturation within the root zone, leading to unavoidable deep percolation losses, which may sometimes be in folds of the original water requirement of rice itself. For instance, if the conventional irrigation mode for rice requires, 1200 mm of water it naturally includes the net consumptive use of rice around 800 mm only, as well as avoidable deep percolation losses, to the tune of around 400 mm, considering negligible runoff loss component from the bund area.

Considering this conceptual water balance, it is reckoned that the deep percolation losses can be minimized or eliminated so that, the water saving by avoiding deep percolation can help increase the irrigation intensity by about 30-40%. Minimization or elimination of deep percolation loss and scheduling irrigation, confining only to Rhizosphere of rice, in accordance with its potential evapo-transpiration or consumptive use, paves the way for the paradigm shift from flood irrigation to micro irrigation.

The aerobic environment of rice cultivation, warrants either a design depth of irrigation water with a design frequency of application, or an equivalent irrigation mode that can permit a balanced application of irrigation water, to replenish the Rhizosphere moisture deficit, on account of localized evapotranspiration. Micro-irrigation systems particularly drip irrigation system embedded with a fertigation mechanism, will be ideally suitable for supporting aerobic irrigation environment for rice production, compared to scheduling irrigation frequencies.

It is apparent from the traditional irrigation scheduling, based on soil moisture deficit, that dry layers are possible within the Rhizosphere, causing adverse effect on the Rhizosphere microclimatology and rice physiology. Micro irrigation systems on the other hand, can help maintain the field capacity status of the Rhizosphere without detrimental, to the rice physiology. In addition, embedded fertigation mechanism will also contribute to a balanced status of nutrient availability within the Rhizosphere. In case of traditional paddy cultivation fertilizers are applied in a predetermined proportion of NPK mixture by way of just broadcasting the fertilizer all over the wet rice field moving in the mud. Green manures are mixed by way of trampling under puddle conditions. Such a practice is vulnerable for non uniformity in fertilizer

application as well as loss of fertilizers out of the field. However, a paradigm shift from the traditional anaerobic rice cultivation facilitated by gravitational flooding to an aerobic environment facilitated by fertigation embedded micro irrigation system, requires an extensive experimentation and corroboration.

The fertigation embedded micro-irrigation system on the other hand will distribute water soluble fertilizers all over the field through emission points, in tune with water distribution efficiency of the system, minimizing the labour requirement and losses of fertilizer application.

MATERIALS AND METHODS

The paradigm shift of rice cultivation under traditional anaerobic environment, towards an aerobic environment, supported by fertigation embedded micro-irrigation systems warrant different kinds of materials to be used and methods to be adopted for evaluation.

Location of Study

Field experiments were conducted in Wetland, Central Farm of Tamil Nadu Agricultural University, Coimbatore. The farm is located in the North-western tract of Tamil Nadu at 110 N latitude, 770 E longitudes and at an altitude of 426.72 m above Mean Sea Level.

Climate and Weather

The minimum required agro-meteorological variables recommended for fundamental research in rice by World Meteorological Organization and the International Rice Research Institute (IRRI) were considered in the present study. From the meteorological data recorded in the department of meteorology TNAU, Coimbatore, the 60 year average weather data were collected.

The relative humidity ranges from 61 percent (14.22 hrs) to 90 percent (07.22 hrs). The mean bright sunshine hour per day was 7.4 hours with mean solar radiation of about 429 cal cm^{-2} day^{-1}.

The maximum and minimum temperatures recorded during study period were 37.7 0C and 15.6 0C respectively. The maximum and minimum sunshine hours were found as 10.8 and 0.2 hours per day respectively.

The lowest and the highest evaporation rate were found as 1.6 and 7.4 mm per day and the corresponding solar radiation values were recorded as 257.3 and 348.4 cal cm-2 day-1 respectively.

Soil Properties

The soil of the experimental field is sandy clay loam. The pH of the soil is 7.8 and it has a good electrical conductivity of 0.52 dS m-1. The soil has low available nitrogen (284 kg/ha), low available phosphorous (21 kg/ha) and high available potassium (349 kg/ha).The physio-chemical properties of the soil are furnished in Table 1. The bulk density and field capacity of the soil were found as 1.55 g/cc and 30.42 per cent respectively.

METHODOLOGY

The treatments adopted, design and layout of the drip system, planting details, assessment of water budget and water use efficiency and the fertigation schedule are furnished as follows:

Experimental Details

The field experiment was conducted during summer season 2012 using 3 varieties of rice. The experiment was conducted in Split Split plot design

Treatment Details

The treatments are allotted randomly at each plot in the experimental field. The Length and Width of each plot are of 7 m and 2.4 m. The spacing of the crop is 20×10 cm. The details of the treatments are given.

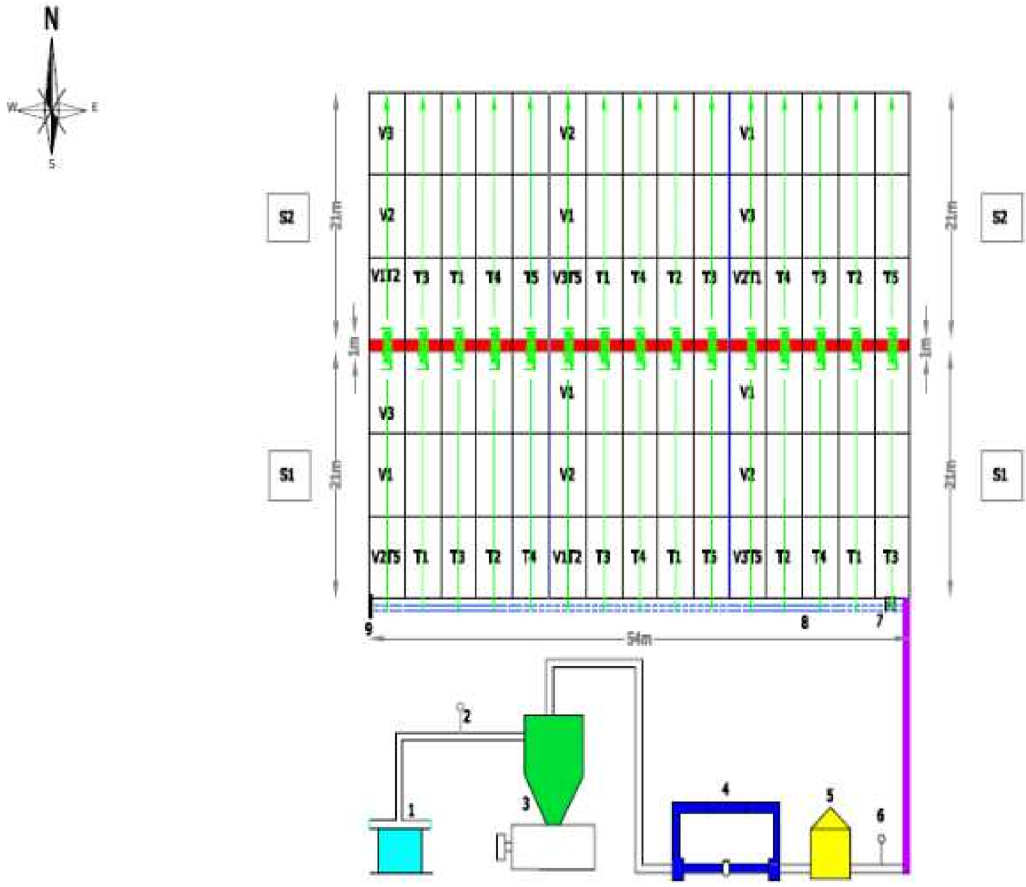

Figure 1: Layout of Drip Irrigation System

1 - Tube well

2 - Pressure gauge

3 - Hydro cyclone filter

4 - Ventury Unit

5 - Disc filter

6 - Main line

7 - Control valve

8- Submain

9- Flush valve

T1- lateral distance 0.8 m and depth 5-10 cm

T2- lateral distance 1.2 m and depth 5-10 cm

T3- lateral distance 0.8 m and depth 15-20 cm

T4- lateral distance 1.2 m and depth 15-20 cm

S1- solar operated pump

S2- well submersible pump

V1- TNRH 180 (Hybrid)

V2- JKRH 3333 (Hybrid)

V3- ADT (R) 45

Cultural Practices

Gap filling was done one week after sowing with the reserved seeds of the same variety. Thinning was done 10 days after sowing.

Soil Analysis

Representative surface soil samples (0 to 15 cm depth) were collected from the different areas of the plot before sowing for determination of soil parameters.

The soil sample was air dried in shade, powdered gently with a wooden mallet and then sieved through a 2 mm sieve. The sieved soil sample was used for the analysis.

Mechanical Analysis

Sieve analysis was conducted by sieving the samples through a set of eight sieves; the size of openings varying from 4.75 mm to 0.075mm. Hydrometer analysis has been performed for the portion finer than 0.075mm or 75 micron. Weight retained in gram and cumulative percentage retained was calculated. The cumulative percentage is plotted against the sieve size to get the particle distribution curve.

RESULTS AND DISCUSSIONS

The scenario of rice production in Tamil Nadu has been undergoing drastic changes with reference to the package of cultivation practices that are specific with traditional anaerobic or the current aerobic options. Under anaerobic conditions the paddy field is always subjected to standing water to a depth of at least 1 cm, inherently permitting 2 to 3 cm of water going down as inevitable deep percolation losses. This trend was possible when the rainfall and water supplies for irrigation were copious and the farmer had a psychological satisfaction of seeing water on the surface of paddy fields with a view of getting more yields with more water. However, the advancements in scientific agriculture have made the paradigm shift towards an anaerobic environment for rice cultivation with a corroborated sustenance of rice yield without the deep percolation losses. Under the premise that “water saved is water earned”, the deep percolation losses that are

minimized or eliminated can help increase the rice cultivation intensities 2 to 3 times under aerobic environment, as supported by fertigation embedded by micro-irrigation systems. In line with the objectives envisaged for the present study the results obtained have been critically analyzed, discussed and conclusions are arrived at as follows.

Design Aspects

The volume of soil wetted from a point of source like surface or subsurface drip emitter is primarily a function of the soil texture, application rate and the total volume of applied water. The drip irrigation is designed to meet the evapotranspiration water requirement of any crop. The hydraulic design of a drip irrigation layout, in tune with the crop spacing and the daily water delivery requirements, is greatly affected by the frictional head losses from head to tail end of the layout. The hydraulic gradients along sub mains and laterals are indicators of gradual reduction in discharges at emission points and the relative distortion in moisture distribution contours and the eventual uniformity of water application and distribution. While most of the row crops with drip irrigation systems get only a partial wetting of their Rhizosphere, rice is supposed to have a complete wetting of its rhizosphere only at field capacity levels, of course, without any deep percolation losses or surface runoff. This is how the basic design for aerobic rice layout is different from other crop layouts.

Plot Designs and Type Designs

The field experiment is confined to a small plot size of (7m x 2.4 m), wherein the observations are related to pressure and discharge variations, may not be appreciable even though other parameters such as plant growth characteristics, water requirements, yields and water use efficiencies may change significantly. Hence, it is preferable to have a type design projected over a unit area of at least 1 ha (100m x100m) to facilitate distinct pressure and discharge profiling.

The type design has been made as follows

Plant population = (100 X 100)/(0.1 X 0.2)

= 500000

Water requirement/day/plant =0.12 lit/plant

Total water required =60000 lit/day

Select an emitter discharge of 2 lit/hr

Duration of irrigation/plant = 3 min 36 sec

Pump discharge = (500000 X 0.12)

= 60000 lit/day

Simulation of Pressure Profile along Sub Mains and Laterals

The type design layout should depict the hydraulic gradients along the sub mains and laterals, in order to calculate the operating pressure heads and discharges at desired emission points, besides drawing the pressure – discharge contours. The pressure profiles generated are based on the hydraulic gradient model formula given below. The pressure profiles have

been generated for every 12th lateral.

Pressure Profile along the Sub Main

The Operating pressure heads along the lateral at different emission points depend on initial operating pressure head, at the junction point of lateral with the sub main, the inflow discharge in to a lateral at a given distance along the sub main, the distance of the emitter away from the sub main, the distance of the lateral along the sub main and away from the main, the size of lateral and the sub main, the values of exponents used for discharge and diameter depending on the frictional formula chosen. For the present study, Darcy Weisbach"s Modified Empirical Frictional Loss formula has been used, as applicable for multi-outlet pipe flow along laterals as well as along the sub main.The head loss due to friction along laterals or sub main will in turn result in decreasing operating pressure heads with a proportionate decrease in the corresponding emitter discharges. For a multi outlet pipe flow, be it a sub main or lateral, the operating pressure heads along the length of flow can be obtained by using the formula, Using the above notions and formulae the pressure profile along the sub main of the type design layout for a unit area of 1ha (100 m X100 m) has been developed.

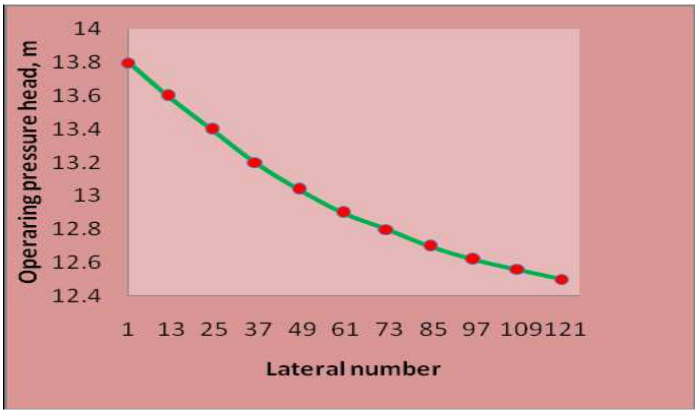

Figure 2: Operating Pressure Head along Sub Main

The variations are clear in case of the type design layout while variations are minimal in case of field plots (2.4 m x 7 m).

The type designs have been arrived at for a surface drip irrigation layout with emitters on the soil surface surrounding individual rice plants.It is quite evident that the operating pressure head decrease gradually along a multi outlet irrigation pipeline such as a drip sub main or a drip lateral, owing to gradual decreases in the total inflow from start to end of the line. Once, schematic rational approach to compensate the operating pressure head decrease, thereby increasing the irrigation distribution uniformity would be to incorporate the exactly same layout of sub mains and laterals from the opposite direction.

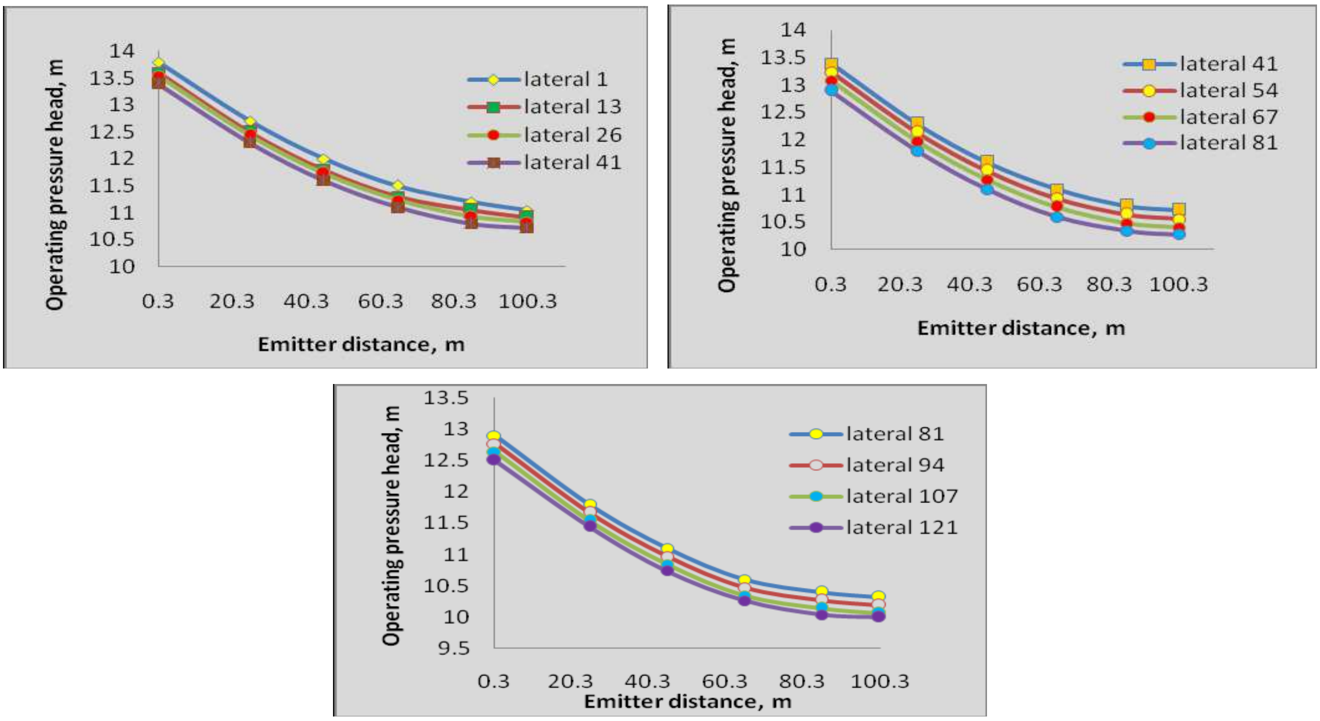

Figure 3: Pressure Profile Generated along Laterals

Even though the cost of the system components will be doubled, the water distribution uniformity all over the field will be high close to 100 %, with a reduction in the drip operation by about 50 %.

This is the only feasible solution to improve upon the water use efficiency under drip irrigation systems applicable for Rice cultivation.

In addition to the clogging problems by drip emission points underneath the ground surface but within the Rhizosphere, incorporation of fertigation with soluble fertilizers along the flow of water will also add to the variations in pressure and discharges.

In the proximity of emission points, accumulation of these fertilizers within the soil pores may also contribute to further clogging of the emitters.

The hydraulic limitations with sub surface emitter clogging problems are also beyond the scope of this study. Hence, the pressure profiles obtained for a surface drip irrigation layout will be distorted for sub surface drip irrigation layout. Since, the present study was executed on relatively smaller experimental plots; the distorted pressure profiles to be projected on a type design scale could not be arrived at.

Frictional Head Loss

The micro irrigation systems, be it a drip system or a sprinkler system, are vulnerable for frictional head loss along the multi outlet or blind pipe segments. For instance, if the initial operating pressure head at the junction point of a lateral with its sub main is, say, 1kpc (10 m of water head), the operating pressure head gradually decreases on account of frictional loss in case of a blind pipe, the discharge through the pipe remains constant.

In case of multi outlet pipes, such as lateral with the drippers or sub main with laterals, the discharge also

gradually decreases towards the tail end of pipe in as much as the total discharge is divided for emitter discharge along the length of flow. Hence, the decrease in discharge through the pipe from emitter to emitter was noticed. Naturally the loss in the pressure head at any point will be compensated by gain in the pressure head due to flow in opposite direction. However the cost of layout will be double but accounting for the benefits approved by the way of achieving nearly 100% of application and high degree of water usage efficiency sustaining the potential yield of rice this factor can be ignored. Exhibit the compensation of frictional losses due to the mirror image of hydraulic gradient created in opposite direction.

Moisture contents were observed in drip irrigated experimental plot at surface, 10, and 20 cm depth and at a distance of 0, 10, and 20 cm distance from emitter on both sides. To determine the soil moisture distribution pattern, gravimetric method was used to evaluate the soil moisture content. The soil samples were taken from three different depths at two different lateral distances from the centre of the emitter. The maximum moisture content was found to be at the location where the wetting circles overlapped by two emitters. The maximum and minimum moisture content was: T1 (27.06, 20.10), T2 (29.63, 19.62), T3 (31.52, 22.19), T4 (25, 20.75). Figure 4.8 which show soil moisture distribution after irrigation by open submersible solar operated pump. The soil moisture was more at 10 to 20 cm depth from the surface of dripper depths.T1 (24.55, 18.43), T2 (24.09, 12.89), T3 (23.87, 11.62), T4 (25.14, 11.70).

Effect of Different Treatments on Yield

The effect of irrigation treatments on the yield of paddy was analyzed. The analysis of data revealed that among the treatments tried, the drip irrigation with 2 lph dripper discharge and 0.8 m lateral spacing was found to be better (6177.1 Kg ha^{-1}) at 5 per cent level of significance, followed by the 2 lph discharge and 0.6 m lateral spacing (T4) giving (5990.2 Kg ha^{-1}).

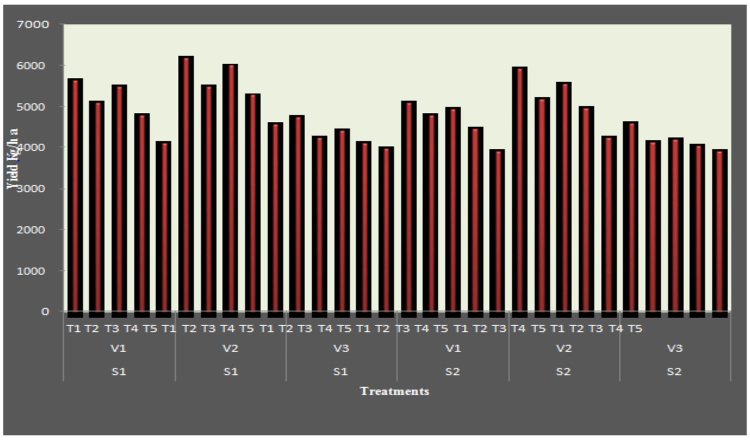

Figure 4: Yield Observed with Different Treatments

Figure 5: Experimental Field at the Stage of Harvesting

Water Use Efficiency (WUE)

The water use efficiency for all the treatments were worked out with taking in to account the amount of total water applied during the crop period. Higher WUE of 8.917 kg ha^{-1} mm^{-1}was recorded in drip irrigation at 0.8 lateral spacing and lateral depth of 5-10 cm and depth of 5-10 cm (T1) with variety 2 and solar irrigation(S2), closely followed by lateral spacing of 0.8 m (T1) with the same variety 2 and well Submersible pump (S2)WUE of 8.542 kg ha^{-1} mm^{-1}. The least WUE (4.361 kg ha^{-1} mm^{-1}) was noted in control (T5). Treatment of 0.8 m lateral spacing at a depth of 5-10 cm with variety 2 by solar irrigation recorded higher WUE. It was because of higher yields obtained due to optimum supply of irrigation water.

In terms of total water used for paddy cultivation, flood irrigated paddy field used 65 lakh litres/acre (Soman, 2009) of water every season which had fallen by nearly 60 percent to 25.74 lakh litres/acre under drip irrigation in the experiment conducted. The amount of water saved can be used to cultivate nearly 2.5 times more area under rice production than the conventional flood irrigation method. Similar results of increase in water use efficiency through drip were reported by Parikh *et al*. (1996). Ramesh (2003) stated that irrigation with drip method produced significantly higher irrigation water use efficiency compared to furrow irrigation and was due to higher yield under drip irrigation. Bouman *et al.* (2007) reported that the savings in water used for aerobic irrigated rice vis-à-vis flooded rice are mostly due to savings in water needed for preparation and seepage and percolation and that reductions resulting from evaporation and transpiration are marginal. Water required for puddling of soil in flooded rice culture is one time requirement independent of the duration of crop field life and season.

Cost Economics

The cost economics calculation related to the present study was done to find the economic feasibility. The life of

the drip material was taken as 10 years, interest at 12 percent of fixed cost, the repair and maintenance cost at 2 per cent of fixed cost were taken in to consideration to work out the cost economics. The fixed cost estimate of drip system with 0.8 and 1.2 m lateral spacing and 2.0 lph drippers and lateral depth of about 5-10 cm and 10-15 cm along with the data on cost of cultivation, fixed cost, seasonal cost and net income for different treatments were depicted. The benefit cost analysis has that revealed the treatment(T1) with lateral distance of 0.8 m and lateral depth of 5 – 10 cm offers the highest level of benefits followed by (T3) With lateral distance of 0.8 m and depth of about 10 - 15 cm in a closer range.

Table 1: Cost Economics of the System

Treatments	T1	T2	T3	T4	T5
1.Life span 10 years	131043.3	106126.7	91176.7	144376.7	0
2.Repair and maintenance cost (2 % of fixed cost*)	2590.9	2092.5	1793.5	2857.5	0
3. Interest on fixed cost * (12 %)	15725.2	12735.2	10941.2	17325.2	0
Total Fixed Cost	149359.4	120954.4	103911.4	164559.4	0
A. For one Year (System cost)	14935.9	12095.4	10391.1	16455.9	0
B. Operating Cost a. Ploughing	280	280	280	280	280
b. harrowing	280	280	280	280	280
c. Bed Preparation	480	480	480	480	480
d. Seed	2500	2500	2500	2500	2500
e. Sowing (Direct Sowing)	750	750	750	750	750
f. Herbicide application	480	480	480	480	480
Table 1: Contd.,					
g. Fertilizer	8011	8011	8011	8011	8011
h. Irrigation	0	0	0	0	0
i. Electricity Charges	1500	1500	1500	1500	1500
j. Gap filling	400	400	400	400	400
k. Spraying	300	300	300	300	300
l. Weeding Operation	2000	2000	2000	2000	2000
m. Bund Strengthening	0	0	0	0	0
n. Harvesting	1500	1500	1500	1500	1500
Total Operating cost	21681.2	21681.2	21681.2	21681.2	21681.2
C. Total production cost (A+B)	36617.1	33776.6	32072.3	38137.1	34916.6
D. Yield (kg per ha)	5353.8	4814.1	5098.3	4601.1	4121.9
E. Total gain (Rs.)	110042	92000	96900	86606	67188.8
F. Net Profit (Rs.) (E-C)	73424.9	58223.4	64827.7	48469	63692.2
Benefit Cost Ratio (F/C)	2.005	1.72	1.95	1.34	1.75

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